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Mental rotations and map use: cultural differences

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Abstract

Earlier studies on Swedish participants using maps in different rotations (north-up, head-up and 3D-egocentric view) has shown that use of head-up and 3D egocentric maps in a maze experiment gives faster decision making and less errors that the traditional north-up oriented map. The assumption is that by removing the need of making cognitively demanding mental rotations, cognitive off-loading will be achieved. A remaining question is whether or not these results in some way would depend on cultural factors such as e.g. education or traditional use of maps.
In a new study done on 32 fourth-years Chinese master mariner cadets at Dalian Maritime University in China the earlier experiment were replicated. The results showed interesting differences: First, speed and accuracy of navigation with only landmarks without electronic position plotting where significantly lower for the Chinese participants, however in the condition with electronic position plotting the results where comparable and in the 3D condition equal to the Swedish test groups. Second, in the trade-off between speed and accuracy, the Chinese participants choose accuracy to a greater extent than did the Swedish participants.

1. Introduction

There is a type of accidents at sea that is characterized by a sudden loss of orientation. They often occur during darkness or fog. Examples of such accidents can be found in Porathe (2006). If we think of the navigation enterprise as a two-folded undertaking, we fist have the strategic route-planning and route monitoring task. This task is best supported by the traditional exocentric north-up map. The other task is the actual conning the ship, the tactical task of driving the ship using the map as a wayshowing devise. In this task the map as a decision support system showing if the ship is on track and the distance and attributes of the next turn is of crucial importance. In Figure 1, a Swedish navy bridge set-up is shown, where the alidade of the pelorus in the front window serves as a reminder of the direction and the angle of the next course.

Fig. 1. The alidage of the pilarus in the front window of a Swedish navy ship serves as a reminder of the next course.

In two previous studies speed of decision-making and accuracy of navigation using maps of different types has been tested. The tested types have been the traditional north-up oriented map, the so called head-up or course-up map and an egocentric view “3D map.” The first study used 40 Swedish students, relatives of students and university staff at ages from 16 to 63 with mixed experience of navigation (Porathe, 2006). The second study used 30 professional navigators, navy high speed combat boat drivers, ship officers and maritime academy cadets (Prison & Porathe, 2007).

In a new study conducted in November 2011, 32 Chinese merchant navy fourth year cadets from Dalian Maritime University was used. The study was a replica of the previous studies and the objective was to detect potential cultural differences in map use.

2. Method

The maze

A 6 meter by 6 meter square was drawn on the floor of a large room. The space was divided into a grid of 10 by 10 grid squares. In this grid a maze was constructed by defining the 100 squares as either Go och NoGo squares. Neighboring Go squares formed a winding path through the maze. This was the "track" of the experiment. A chair, some boxes and a paper tube acted as landmarks to aid navigation. Four different tracks, but equally long and with an equal amount of turns, was designed. One of them can be seen in Figure 2.

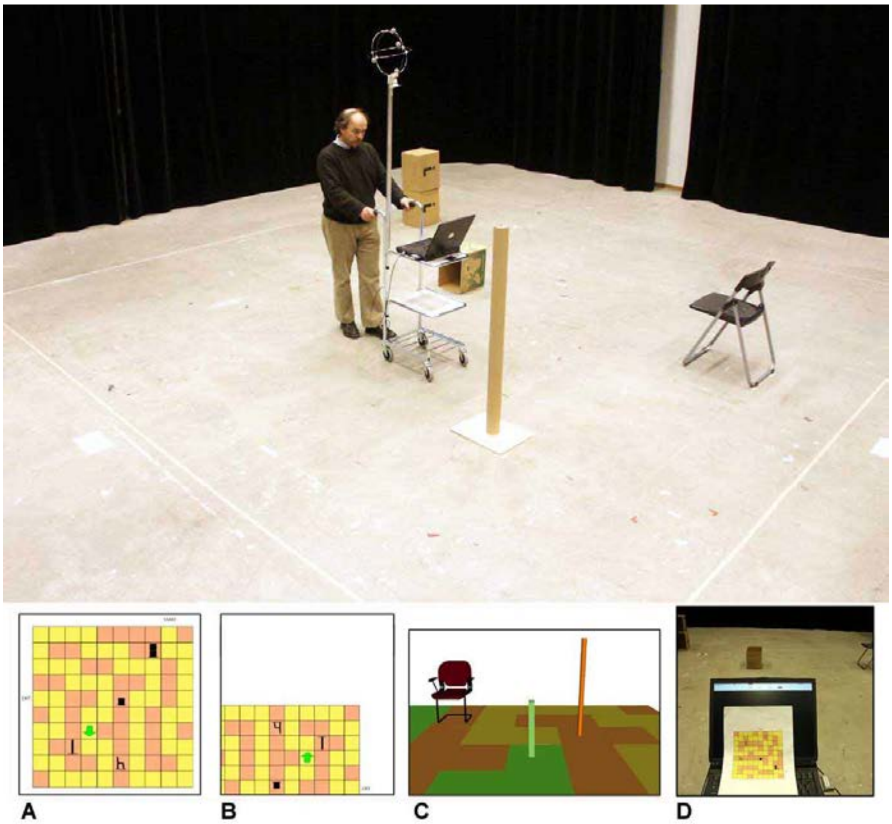


Fig. 2. The experimental design: a 6m by 6m area with four navigational aids and the author driving the cart. The four map types displayed on the lap top screen at this very instant can be seen at the bottom of the Figure.

The tested map types

The different map types for one of the tracks in the experiment can be seen in the bottom part of Figure 2. Through the NoGo area (red/dark brown squares) the track winded (yellow/light brown squares). In all four map designs the length and the number of turns of the channel was about the same. The landmarks were depicted on the maps as well. For each of the four map designs one 2-D map and one 3-D model was constructed.

Four different map types were tested in the experiment (see bottom part of Figure 2):

A. The north-up map. A static exocentric 2-D map was displayed on the screen of the laptop computer fitted on the cart. The map was oriented with north up, but during the experiment the "north" direction in the room was changed for each of the four track designs. The location and heading of the cart was visualized on the screen by a moving green arrow.

B. The head-up map. A dynamic exocentric 2-D map which could translate and rotate on the screen so that the forward direction always was up on the map. The position of the cart was depicted by a static green arrow in the lower center of the screen.

C. The 3-D map. A static 3-D model of the track. A moving green pole marked the position of the cart. The virtual camera supposedly hung on top of and behind the subject pushing the cart showing the egocentric view.
D. The paper map. A print-out of the exocentric 2-D map. The subjects held the paper map in their hand while pushing the cart with the other. The could use it head-up or north-up as they wished. The screen was black.

The vehicle
The cart used in the experiment covered a ground plane of 0.45m by 0.38m. All four of its wheels could rotate, making the cart easy to maneuver. The cart had a shelf on which a laptop computer was placed. The computer ran on batteries so no cords were attached to the cart during the experiment. The computer was fitted with a custom-made real-time 3-D software application that was used to show the 3-D egocentric maps, the 2-D exocentric north-up and head-up maps. This application also monitored the movement of the cart and logged time it took for the subject to finish each track and the number of "groundings" made by the subjects (the cart entering into the red squares).
The coordinates of the cart (x, y and heading) was sent from an infrared tracking system by wireless LAN and received by the laptop to mimic a GPS system. The uncertainty of the system setup was less than 0.02m. The update frequency of the tracking system was 50 Hz.

Test subjects
Study 1: 45 subjects were volunteers from a population of available students, teachers and personal at Mälardalen University (MDU); 24 male and 21 female, ages 16 to 63.
Study 2: 30 male subjects of age 22 to 54. 18 were navy officers with experience of high-speed combat craft navigation, 6 of the test subjects were experienced bridge officers from the merchant navy and 6 were fourth year cadets from the maritime academy at Chalmers University of Technology (CTH).
Study 3: 32 fourth year cadets from the maritime academy at Dalian Maritime University (DMU) in China. Age 20-24.

Experimental set-up
Each subject drove the cart four times through the four different track designs. The order of these designs was always the same. For each time they used a different map type. The order of the map types was balanced using a Latin square design to as much as possible prevent learning effects to influence the results. So one subject might start out with the egocentric 3-D display on track 1 and the next subject might start out with the paper map on the same track.

Efficiency scores
The test subjects were instructed that the purpose was to drive the cart though the track "*as fast as possible with as few errors as possible*" (entering into the red areas on the map). It was explained to the subjects that this was no competition; the experiment was to test the efficiency of different maps, not the skills of the participants. They should pick a strategy (from quick and sloppy to slow and careful) that they felt comfortable with and try to stick to that same strategy throughout the experiment. Then they were guided through a practice session. When the subject felt ready, the experiment started.

Self-ranking of ease of use
After the sessions a short interview took place. The subjects were asked about their previous navigation experience and they were asked to fill in a ranking form where they ranked the four map types after ease of use from 1 to 4 where a 1 meant the easiest and a 4 the hardest map type to use.

Translations into Chinese
In the Chinese study all instructions where translated to Chinese to ensure that the understanding as much as possible was the same. Eight English proficient Chinese master students from the Interaction Design master's program at Dalian Maritime University helped with the setup of the experiment, with

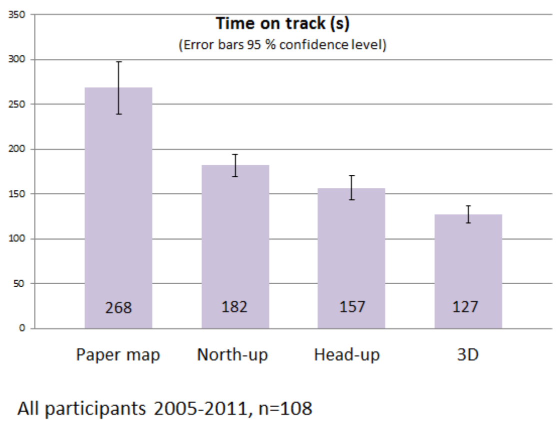
translation and with dong the instruction and interviews in Chinese and afterwards translating them back to English.

3. Results

The result of the two earlier studies has been published elsewhere and the details of those can be found in Porathe, 2006 and Prison & Porathe, 2007. The result of the Chinese study is for the first time published here.

Efficiency scores

If we start with looking at the merged results from all three studies 2006-2011 for the two parameters, time-on-track and number of errors, we see that the condition with no on-screen positioning and only a paper map is the one which generates the longest time-on-track, and the greatest number of errors (268 seconds in mean and 9.2 errors).



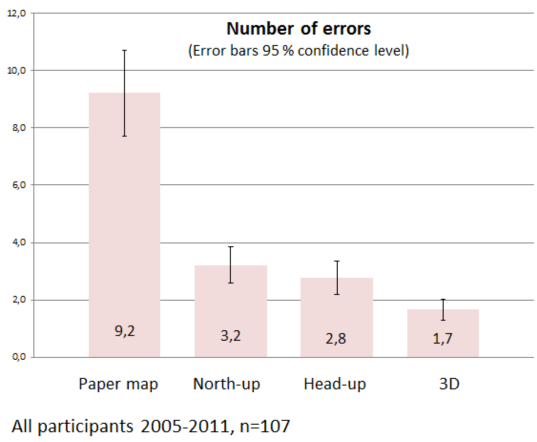


Fig. 3. The diagrams show mean results for all three studies during the time period 2006-2011.

Among the electronic map conditions, the north-up map is also the slowest and most error prone (182 seconds and 3.2 errors). The head-up condition is somewhat more effective with 157 seconds and 2.8 errors. In this study the 3D egocentric condition is the one generating the fastest time-on-track with 127 seconds and fewest errors with a mere 1.7 errors. All differences are statistically significant except the error difference between north-up and head-up conditions.

In the two diagrams in Figure 4 and 5 the result from the three studies are split up with the three different groups side by side. The yellow bars (leftmost in each column) represents results from the 2006 Swedish study with amateur navigators at Malardalen University, the green bars (middle in each column) represents the results from the 2007 Swedish study with expert navigators at Chalmers maritime academy and the blue bars (rightmost in each column) represents the results from the 2011 Chinese study with expert navigators at Dalian Maritime University.

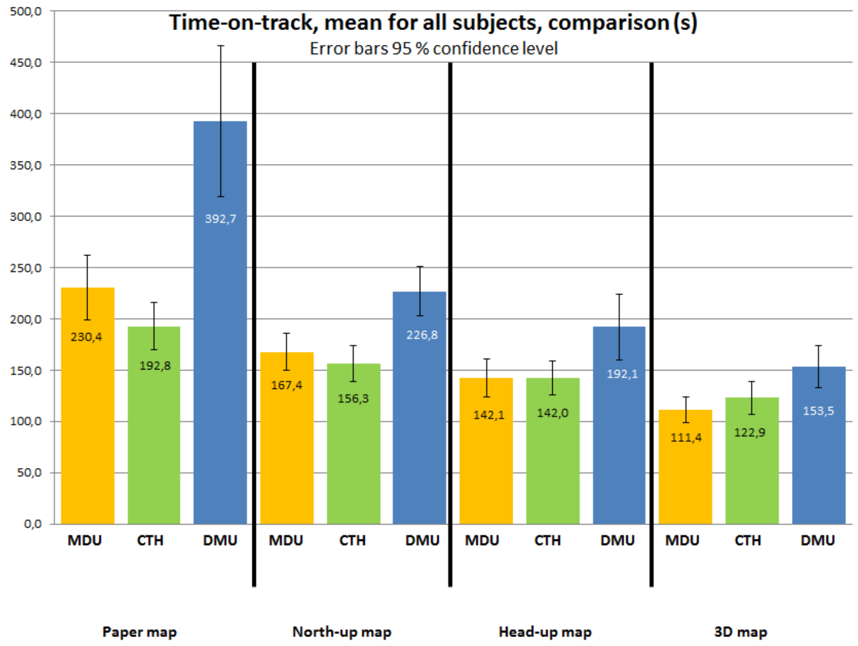


Fig. 4. The diagrams show mean time-on-track for all three studies during the time period 2006-2011.

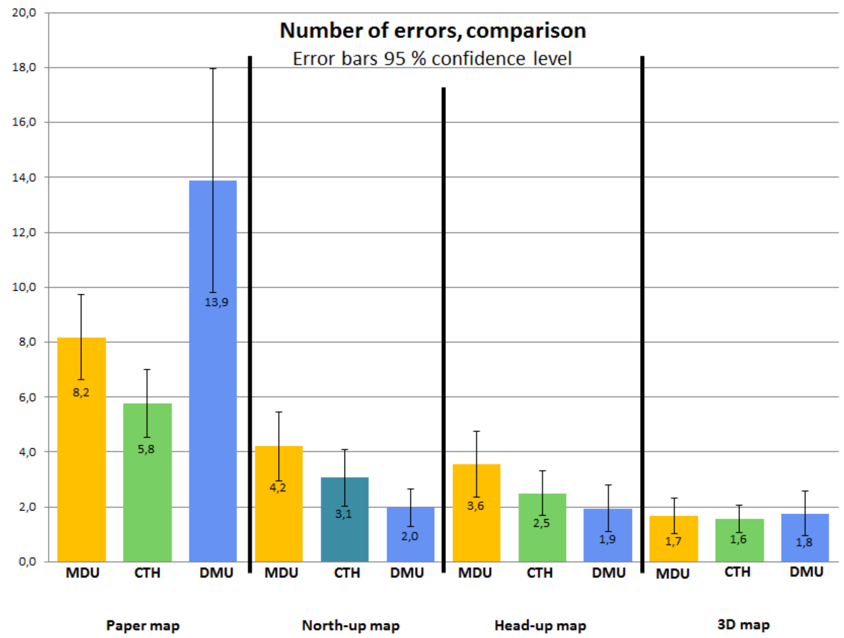


Fig. 5. The diagrams show mean errors for all three studies during the time period 2006-2011.

All Figures are also presented in Table 1 below using standard deviation (SD) as measure of variance instead of 95 % confidence level as in the diagrams. The result of the analysis of variance (ANOVA) is also presented in the table. As can be seen there is a significant effect of the group variable (MDU, CTH and DMU) except for errors in the head-up and 3D conditions.

Tabel 1. Tabular presentation of data in Figures 4 and 5.

	Mean time on track (seconds)				Mean number of errors			
Groups	**Paper (SD)**	**NU (SD)**	**HU (SD)**	**3D (SD)**	**Paper (SD)**	**NU (SD)**	**HU (SD)**	**3D (SD)**
MDU	230 (105)	167 (60)	142 (61)	111 (42)	8.2 (5.1)	4.2 (4.1)	3.6 (3.9)	1.7 (2.1)
CTH	193 (61)	156 (48)	142 (44)	122 (43)	5.8 (3.3)	3.1 (2.8)	2.5 (2.1)	1.6 (1.4)
DMU	393 (205)	227 (67)	192 (88)	153 (57)	13.9 (11.3)	2.0 (1.9)	1.9 (2.3)	1.8 (2.3)
All	268 (158)	182 (66)	157 (70)	127 (50)	9.2 (7.9)	3.2 (3.3)	2.8 (3.1)	1.7 (2.0)

Table 2 presents the results of a two factor ANOVA showing significant effects of map types on both the time and error variables. The analyses also show a significant effect of the group variable (MDU, CTH and DMU) on both time and error. The analysis also shows a significant interaction effect between the group and the map type variables.

Tabel 2. Results from significance test of interactions (two factor analysis of variance)

		Time			Error		
	df	**F**	**Sig. (P value)**	**Partial Eta Squared**	**F**	**Sig. (P value)**	**Partial Eta Squared**
Groups	2	40.557	< 0.0001	0.163	4,745	0.0092	0.023
Maps	3	53.703	< 0.0001	0.279	64,530	< 0.0001	0.320
Group*Map	6	5.130	< 0.0001	0.069	9,302	< 0.0001	0.119

The test results presented in Table 2 shows that there is an overall significant difference between the groups in the study. Post hoc tests show that there in some cases is no significant difference between for instance the error rate of the three groups in the 3D condition (see Figure 5). But these cases can be approximately identified considering the error bars in the diagrams in Figure 4 and 5.

Self-ranking of ease-of-use

The results from the self-ranking of ease-of-use are presented below. Each participant ranked the four map types from 1 to 4 where 1 was the easiest and 4 the most difficult map type to use for the task. For each map type the mean score was calculated and is below presented along a line where easy is to the left and difficult to the right. The results from all three groups conforms, the 3D map was considered the easiest, then the head-up map and the north-up map. With the paper map considered as the most difficult (see Figure 6).

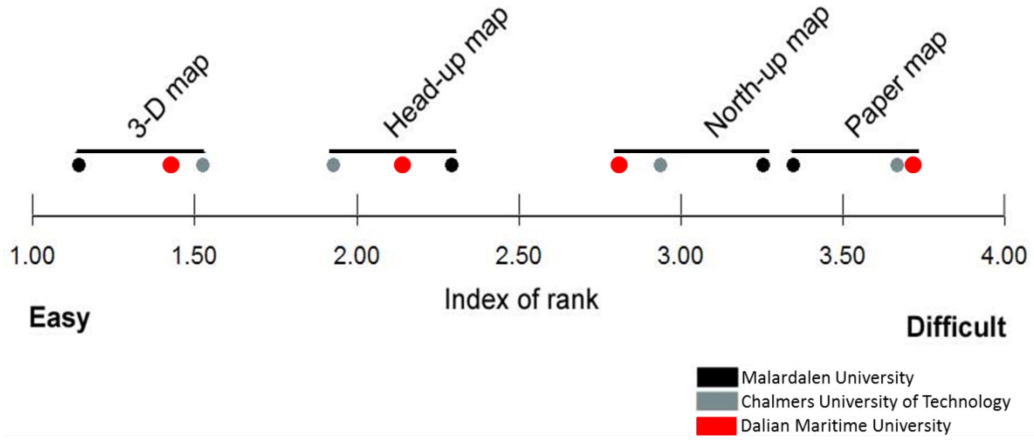


Fig. 6.The results from the self-ranking of ease-of-use. The numbers are an index where 1 means the easiest and 4 the hardest map type to use.

4. Discussion

When observing the participants driving in the maze it becomes clear that the time difference is due to the confidence in which they made each turn, whether it should be to the left or to the right. The most mistakes and errors occurred when going “down” (or “south”) on a north-up oriented map. In this case a left direction on the map was a right direction in the world. The mental rotation needed to use the map as a wayshowing devise resulted in a very high work load and when probing the participants by asking questions we got no answers when they used the north-up conditions (paper map and north-up map). In the 3D condition participants had no problems talking and navigating at the same time.

It was obvious from the first two Swedish studies that speed and accuracy increased when the participants did not need to use mental rotations to use the map. The head-up orientation was faster with fewer errors than the north-up and the 3D egocentric view was the fastest and the least error prone.

Comparing the results between the Swedish amateurs in the first study with the professional navigators in the second study shows that the professionals handled the traditional north-up orientation that they were trained on better than the amateurs, but the differences between the groups ceased with the 3D view suggesting that with this kind of wayshowing aid the need for training became less important.

Cultural differences
Comparing the results from the two Swedish studies with the Chinese study we see that the overall trend is the same. Paper map without positioning is the most difficult, and then north-up, head-up and 3D being the fastest. There are two significant differences however. The first difference that strikes is the long times it takes for the Chinese students to navigate through the maze using only a paper map. In this condition the participants must infer their position in the maze by comparing bearings to the four landmarks. For the Chinese cadets this took longer time and generated more errors than for the participants in the earlier studies. One explanation to this difference could be educational background; differences in the school curriculum in Sweden and China. The paper map condition particularly taxes some basic navigational skills that are taught to school children in Sweden in the sport of orienteering where competitors try and find *controls* hidden in a wood. These places are beforehand marked on a map and the task is to find them as quick as possible using the map and landmarks in the nature. Any comparative type of map training is not given to Chinese school children, according to discussions had with the Chinese researcher group at Dalian Maritime University.

The other noticeable difference is the low and even results on number-of-errors in all three electronic map conditions for the Chinese participants. In mean the Chinese participants had only two errors on north-up, head-up and 3D. We can still see that it is harder to reach this high accuracy rate in north-up compared to e.g. 3D because there is a penalty in lower speed. But while the Swedish participants balanced the speed accuracy trade-off, the Chinese participants concentrated on making fewer errors.

It is interesting in these studies to see how the balance in the trade-off between speed and accuracy is handled. Hollnagel (2009) calls this ETTTO – the Efficiency-Thoroughness Trade-Off. The task in this study is an example of a *double-bind* (“go as fast as possible with as few errors as possible”). When people are faced with a task where two goals cannot be satisfied at the same time they usually try to find a strategy of balancing speed and accuracy. The Chinese participants in this study seem to have a different strategy when it comes to this trade-off, putting greater emphasis on accuracy than on speed. Hollnagel has an interesting discussion about *tractable* and *intractable* societies and organizations in the book mentioned above. This could be a possible explanation.

In this driving task the results suggests that the differences in training (as between the Swedish amateurs and professionals) and culture (as between the Swedish and the Chinese groups) gets smaller as the demand for cognitively taxing mental rotations lessens. In the 3D condition the differences in results from all three groups are smallest. The analysis of variance also shows that there is a significant effect of the groups, except in the error measurements of the head-up and 3D conditions. My suggestion is that the 3D map type is an example of "accessible design" which circumvents differences in training and culture in tactical wayfinding tasks.

A possible implementation of these results in a maritime navigation context could be to introduce a 3D egocentric view conning display. Not as a replacement for the ordinary exocentric north-up map, which is needed for strategic tasks like planning and overview, but for short term tactical decision-making. Figure 7 show such a possible set up.

5. Conclusions

Earlier studies with Swedish amateur and expert navigators has shown that speed and accuracy in a wayfinding task is enhanced if map presentations needing less cognitively demanding mental rotations is used. A new study with Chinese merchant navy cadets confirmed the results from the earlier studies. Some cultural differences were found, but the major conclusion is that the 3D egocentric view map presentation mode seems to have the ability to circumvent differences in training and culture and be just as efficient for all groups tested.

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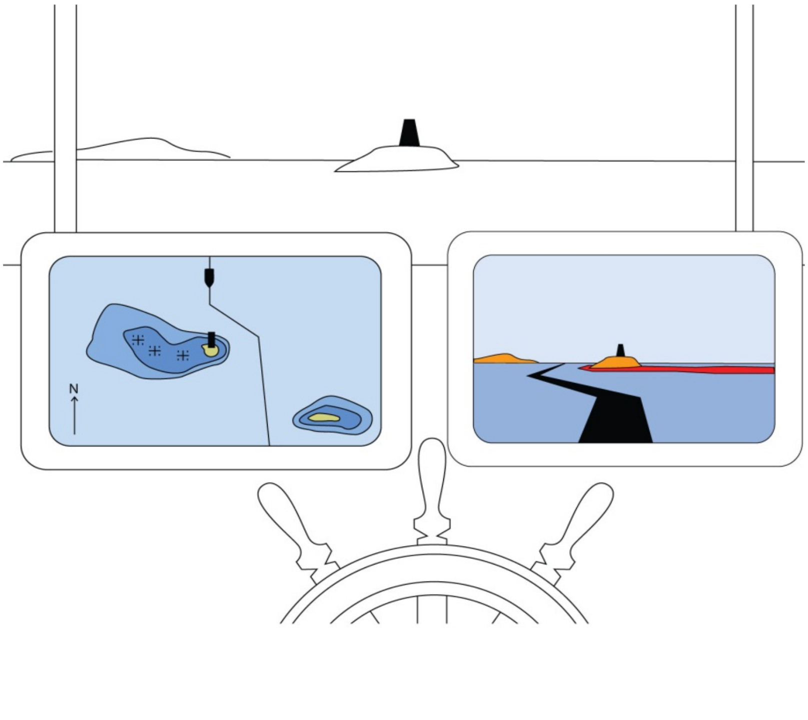

Fig. 7. Two different map views: both needed. To the left the traditional north-up strategic map rotation, needed for route planning and overview. To the right an egocentric 3D map which facilitates decision-making in the tactical piloting task. (Illustration from Porathe, 2006)